III. SIMULATION BASED ACQUISITION

A. Introduction to Simulation Based Acquisition

M&S tools have been used to support the systems acquisition process, both in DoD and elsewhere, for a long time. As dramatic advances in the supporting technologies made those tools more powerful and less expensive, and as declining resources and changing priorities made it essential to find better ways to develop and field new systems, the use of these tools and of improved processes that exploit their contribution has expanded rapidly. It is not the purpose of this report to justify why the emerging M&S tools and processes should be used, but rather to cite documented contributions to the total acquisition process.

This use of M&S tools has increased in an evolutionary manner so that many would observe from their experience that 'nothing has changed, we have always used M&S tools.' In fact, much has changed and the rate of that change is increasing rapidly. This increase has not been imposed by fiat; it is not the result of new guidance or direction from top management. Rather it is the result of piecemeal adoption of powerful new emerging M&S tools to support existing processes and to satisfy emerging requirements.

As a result, these tools have been employed differently by acquisition programs at various stages of development in a seemingly ad hoc manner. Some programs are little changed from their processes of a decade ago while others are being radically transformed by changing processes that depend upon these tools. Most programs fall in-between, using M&S tools at some stages of their program's development with modification of existing processes. Program managers are utilizing M&S tools in areas where they see the greatest benefit.

Although it is not clear where this will lead the acquisition community in the next decade, it is clear that a revolution is underway and that the end result will be a new way of doing business. We will call this new approach to acquisition, "Simulation Based Acquisition," in order to differentiate it from the traditional approaches (Chapter II) and to emphasize its reliance on the tools and processes made possible by advances in simulation technology. It is not presented here as a specific, definable concept, but rather as a term to characterize the general approach of significantly increased use of M&S tools and the new processes which they enable in a new, more integrated approach to program development.

One area that can be impacted in a positive manner by the new acquisition approach is life cycle cost. It is well established that a large percentage of total system cost is determined by initial design decisions. Early system research and development (R&D) is usually only about 10% of total system cost but establishes the level of future production and operations cost. Relatively small investments, one or two percent of the life cycle cost of the system, could result in significant savings (greater than 25%) over the system's life. The traditional acquisition approach lacked the tools to conduct "what if" analyses to determine the impact of design decisions on future cost. These types of tools are now available.

The charter of this study was to document metrics, benefits, and problems associated with the use of these M&S tools in the acquisition process. To keep this effort focused, system requirements analysis and training and training device development were not included in the scope of this tasking. The programs investigated in this effort were at different stages of development, with none having used these tools yet in an integrated fashion throughout their development cycle. This study is consequently a series of independent stories, told in a familiar context. That framework is the acquisition process: concept development, engineering design and analysis, test and evaluation, manufacturing, and deployment and support.

The Simulation Based Acquisition (SBA) approach can generally be characterized as more flexible and integrated than the previous approaches which are often thought of as stovepipes. In a conceptual way, Figure III-1 shows the functions of the acquisition process without the fixed boundaries and with emphasis on their concurrent, integrated development. There is increasing interaction among all of the functions, a genuine concurrent approach, with data and expertise being shared and interacting throughout the entire process.

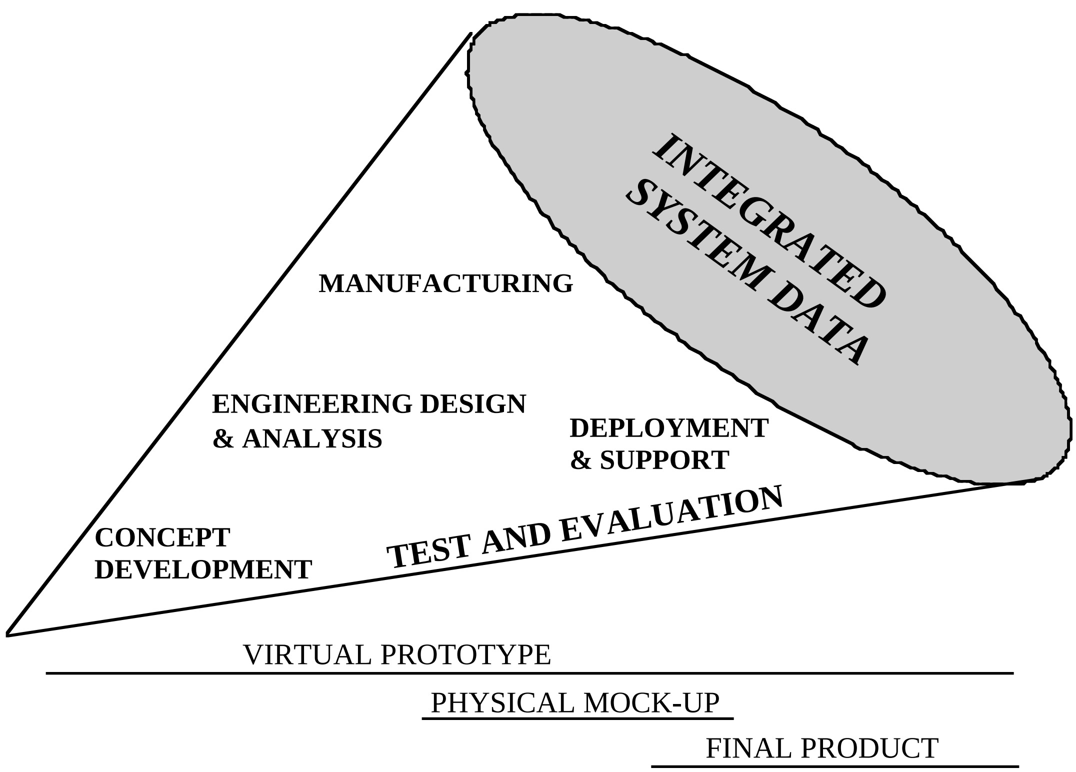

Figure III-1. Simulation Based Acquisition

The savings in simulation based acquisition are not always easy to quantify. As more programs document their success and experience using M&S in the acquisition process, there emerge four bins into which these measures of effectiveness can be categorized. These four areas of realized benefits are cost, schedule, productivity, and quality/performance.

It is worth noting that many reported cost savings are often illusionary. They are typically more correctly classified as "cost avoidance." As such, they are measures of significant additional work or results that were obtained using the M&S tools which would have cost the reported "savings" if they had been obtained by more traditional methods. This study has been careful to differentiate between cost savings and cost avoidance and to clearly identify the latter category when reported. Even if cost avoidance "savings" should not be properly measured in dollars, they almost always are an indication of improved system quality or performance or lowered program risk (e.g., smarter testing). In some cases, the program itself would not be economically feasible without these improved methods which provide adequate risk reduction for an affordable cost.

The approach of this chapter is, for each function of the development (systems engineering) process, to:

- describe how M&S tools are changing the acquisition process,
- identify metrics which validate the effectiveness of these tools in this process, and
- relate specific quantified examples of benefits of M&S tools in this process.

While the following benefits are described within a functional area because of their similarity, and to emphasize the value of M&S tools and processes within that function, it is recognized that product cycle time is a major (top level) metric of great significance. For example, the US automobile industry (Big Three) report that with use of M&S tools and processes, they have reduced the cycle time (from concept approval to production) from five years down to three years, and expect significant further reductions. Electric Boat has reported reducing the cycle time for submarine development from 14 years down to 7 years.

The next chapter will relate technical, cultural, and managerial challenges which prevent programs from realizing the full benefit from these M&S tools.

B. Concept Development Process

Concept development is the analysis of operational requirements and their transformation into functional requirements for a new system. Alternative approaches to satisfying the requirements are evaluated to select the best general approaches to a system solution.

1. Tools in the Evolving Concept Development Process.

Because this stage of development is, by nature, almost totally conceptual, it has always relied upon graphical and data representations (models) of proposed alternatives. Computer tools to support this process have benefited from the recent growth in power and reduction in price of hardware and software which allows the cost effective analysis of far more alternatives than was possible previously. More significantly, M&S tools have benefited from efforts to integrate related tools which enable more extensive analysis of alternatives in a more realistic operational environment. Though the operational environment is virtual, recent progress in developing and making available appropriate realistic and validated virtual environments has been significant and provides the necessary credibility to emerging processes that use these tools.

The ability to develop digital master product models with Computer-Aided Design/ Computer-Aided Manufacturing/Computer-Aided Engineering (CAD/CAM/CAE) software technology has made it possible to more fully understand products from a manufacturing standpoint during the early design stage. The depth and richness of the product information contained in a digital master model makes it easier to more fully communicate detailed information to everyone involved in the product development process.

Digital master models help to develop and evaluate multiple design concepts so that the material solution most efficiently meets user needs. Quality becomes part of the design process itself and can be built-in instead of added-on. Digital master models provide details about the product's shape, behavior, and cost before the fabrication of costly physical prototypes, and help minimize scrap, reduce downtime, and eliminate wasted or redundant operations. This approach allows teams to work concurrently by providing common ground for interrelated product development tasks. Instead of individuals creating one piece of information at a time, the digital master model enables various disciplines to work together much earlier in the product development process.

One intangible, but important benefit of the new M&S tools is the ability to quickly and effectively communicate information on how a new concept will look and function to senior decision makers.

2. Metrics.

- money/effort saved in programs that are canceled/terminated early
- rapid and early proof of concept prior to more detailed stages of design
- better input from users on the impact of concept design decisions

3. Benefits of M&S.

a. Several joint and Air Force warhead/munitions programs were terminated early in concept development, before expending resources wastefully, due to improved analysis of system lethality using M&S tools:

- Wide Area Anti-Armor Munitions (WAAM) - $30M program,
- Hypervelocity Missile - $10M program,
- Kinetic Energy Penetrator (KEP) - $50M program,
- JP-233 Runway Attack Munition - $54M program, and
- Boosted Kinetic Energy Penetrator (BKEP) - $130M program.

b. Vehicle concepts have been terminated or not further explored due to mobility, firepower, or vulnerability problems discovered early using TARDEC's Tracked Vehicle Work Station (TVWS), which creates and evaluates new concepts in a virtual environment.

c. Several Navy programs (NSSN, LPD-17) have explored initial concepts for overall viability and crew/functional acceptability (sizing, location) prior to further design effort. Examples are crane selection and helicopter control station window design for the LPD-17, along with assessments of cargo locations and on-board vehicle movement. For NSSN, maintenance accessibility for personnel and for machinery removal was evaluated early in the design.

d. The Department of Energy (DoE) at Oak Ridge, TN, reported analyzing many 'bright ideas' with M&S tools since they were too expensive to physically check out. Ultimately, all the concepts were rejected as flawed based upon these analyses.

C. Engineering Design and Analysis Process

The design process is well understood from its long tradition of engineering education and experience. The graphical and computational tools that support it have evolved slowly, but the computer revolution has also enabled significant changes in recent years. Slide rules have essentially disappeared for faster and more reliable computational tools, but engineering drawings and representations of components, subsystems, and systems as a means to communicate system design are still widely used.

1. Tools in the Evolving Engineering Design and Analysis Process.

This past decade has witnessed the emergence of computer tools to assist this process, primarily in the domain of CAD/CAM/CAE tools. These tools automated some of the manual tasks of developing graphical and data representations of systems, but they remained at the individual engineer or small functional design team level of use.

Driven by the commercial marketplace, these CAD/CAM/CAE tools have improved greatly, but it is the integration of these tools and the changing of processes which utilize these tools that is beginning to produce significant results. When the entire design team, to include manufacturing, support, and test activities, as well as subcontractors, are linked in a meaningful fashion to this common database, a genuine concurrent approach to development is possible. The various members of this design team no longer need to be collocated. Technology now allows each to work from their own locations in an effective, distributed manner. Far more design alternatives can now be developed and analyzed for performance and cost impacts before finalizing design decisions.

In addition to an integrated team approach to system development, as confidence in the validity and accuracy of these tools has increased, the requirements for elaborate and expensive physical prototypes of the new system have relaxed. Very expensive physical prototypes are no longer the only way to ensure that integration and fit requirements have been satisfied. Virtual prototypes are proving to be acceptable representations for evaluation of many system integration issues.

2. Metrics.

- number of people required to accomplish design tasks
- time required to accomplish design tasks
- number of physical mockups or prototypes that are required
- number of parts or complexity of the final design (i.e., simplicity)
- reduction in first article assembly effort

3. Benefits of M&S.

a. In the DARPA Initiative for Concurrent Engineering (DICE) program, TRW Corporation redesigned a radar warning system using two different approaches: traditional and concurrent design with integrated design automation. The traditional approach required 96 man months while the advanced approach required only 46 man months.

b. TARDEC prepared an engine replacement analysis for the Bradley Fighting Vehicle (BFV) system using half a man month with M&S tools compared to the traditional approach which required 4-6 man months to accomplish.

c. TARDEC designed a new low silhouette tank prototype using 14 engineers in 16 months. Traditional approaches have required about 55 engineers and 3 years.

d. General Electric used a new parametric modeling approach to design a new engine fan blade, thereby reducing the process time from up to four weeks to a few hours.

e. New integration techniques employed by Martin Marietta (now Lockheed Martin Corporation) using M&S tools and processes resulted in:

- reduction of engineering time to construct mock-ups from 2,100 hours to 900 hours ,
- cutting the number of tool designers required from 10 to 4,
- reduction of physical electronic board development iterations from 2.5 to 1.5, and
- reduction of the number of changes per final drawing from 4 to 2.2 for a savings of about $108M per year.

f. Lockheed Martin used solid modeling and computer simulated assembly for aircraft parts design which allowed:

- elimination of some physical mockups at $30M each,
- cost reduction in design/verification steps of 30-50%, and reduction in first article (and subsequent) assembly costs of 20-25%.

g. The AS400 computer development program by IBM used extensive simulation and cross-functional teams to simplify design and reduce the part count to 4000 as opposed to 10,000 for the earlier S/38 computer. They used a simulator to test software design alternatives until they converged upon a virtually defect-free design, and did this in about two years -- less than half the time required for its predecessor machine. About 10 months of the two-year design cycle reduction was due to the use of design simulation.

h. Through advanced integration techniques, Motorola achieved the following gains:

- a 50% reduction in design cycle time for end products using Application Specific Integrated Circuits,
- five-week to one-week reduction in printed circuit board supply and assembly cycle,
- cellular communications product cycle reduced 50%.

i. Sikorsky Aircraft employed 38 draftsmen for approximately six months to produce the working drawings of the CH-53E Super Stallion aircraft's outside contours. The same task on the Comanche program only required one month for one engineer using M&S tools. In addition, precisely designed parts from different contractors assembled properly on the first attempt and required a minimum amount of rework.

j. The Comanche PM Office mandated early use of mission and engineering simulators to examine operational characteristics. The Comanche Simulator and Surrogate Aircraft Fly-Off for source selection cost about $20 million, versus about $500 million for the prototype aircraft fly-off for the UH-60 Blackhawk.

k. Seakeeping analysis in support of ship design by Naval Sea Systems Command (NAVSEA) in 1985 took about 27 days. In 1994, the same analysis was conducted in 3.5 days using better M&S tools operating interactively.

l. Radar cross section (RCS) analysis and treatment for ship design by NAVSEA took about 57 days in 1990. Using new M&S tools and processes, the Navy now can conduct the same analysis in 16.75 days.

m. Newport News Shipbuilding reported improved M&S tools and processes reduced engineering design time by 40% and tooling time by 23-27%.

n. Boeing designed a new strut for the 767 using an all-digital data process in 17% less time, saving 30,000 man-hours, than previous approaches. They also had a 65% decrease in design changes.

o. LPD-17 saved $6 million in design costs by using new M&S tools. It also saved 100 tons in topside weight which is expected to greatly improve performance.

p. Boeing's 777 program exceeded its goal of reducing change, error, and rework by 50%. Parts and systems fit together better than anticipated and at the highest level of quality. On the first 777 aircraft assembled, the final body joining tolerance was just 0.023 inch away from a perfect alignment compared to the typical half inch experienced in previous programs.

D. Test and Evaluation Process

Testing new systems has long involved using the production hardware in a live environment. Testing of defense systems for their ability to meet operational requirements has emphasized the use of typical operators in an operationally realistic scenario and environment. The increasing use of simulators to focus the scope and reduce the cost of testing actual hardware and software demonstrate early movement toward the incorporation of M&S tools and processes.

1. Tools in the Evolving T&E Process.

The senior levels of the Defense Department are now consistent in their support of increased use of M&S tools in the T&E process because of the promise inherent in those tools to help meet the challenges of reduced resources mentioned above as well as focusing the scope and improving the quality of the test process. In recent years there has been continuing dialogue about how to best incorporate those tools, with the underlying issue of the credibility of the tools being a major constraint. At a minimum, the early involvement of the T&E engineer in the concept development stage, to ensure that functional requirements are formulated in a testable manner, is facilitated and aided by M&S tools. Similar tools are now widely used to plan, rehearse, extend, and evaluate live T&E activities. To a significant extent, assessment of a system is now possible using M&S long before a physical prototype is actually constructed. Physics-based dynamic models using CAD descriptions of the system in a test-validated environment now provide critical feedback to system designers, as well as users, as the design matures.

For example, the first flight of a new aircraft is preceded by years and hundreds of millions of dollars of mathematical modeling, flight simulations, hardware-in-the-loop (HWIL), software-in-the-loop (SWIL), and other simulations.

M&S is being integrated with testing as part of a strategy to provide information regarding risk and risk mitigation, to provide empirical data to validate M&S, to permit an assessment of the attainment of technical performance specifications and system maturity, and to support determination of whether systems are operationally effective, suitable, and survivable for intended use. In operational testing, M&S is used to complement the testing of systems in an operational environment by extending the scenario or the environment to make it possible to assess additional situations.

The Air Force Flight Test Center (AFFTC) at Edwards AFB reports a situation common to other Research, Development, Test and Evaluation (RDT&E) Centers and PM Offices. The "savings" resulting from use of improved M&S tools and processes is not realized in dollars, or in less test flights or test time, but rather used to address additional issues that otherwise would not be tested because of limited flying hours and resources available.

One of the primary benefits, especially for aircraft test centers, is avoiding the "cost of failures." This cost avoidance is extremely important to the development programs, and includes the incalculable cost of risking the loss of life of test personnel. The following hypothetical example of a missile program will illustrate some aspects of the "cost of failure."

Assume that: a flight failure causes a two month program delay; the cost associated with this delay is the monthly spend rate times two; the monthly spend rate is $5 million; 40 live missile flights are required for the test; there is a 90% success rate of missile flights. Then a two month slip will cost the program $10 million and four failures (40*[1-0.9]) are expected for a total program cost of $40 million. If the M&S tools are able to prevent half of the failures, a cost savings of $20 million is realized.

2. Metrics.

- number of areas assessed that are difficult/impossible to test physically due to limitations in cost, time, or manpower, or due to risk to humans, equipment, or the environment
- quality and quantity of test data gathered
- amount of testing concurrent with development
- stimulation realism (creating a realistic number of effects with fidelity)
- cost avoidance (for test article as well as test resources)
- number of programs retained (i.e., avoid program termination)
- number of safety problems resolved before human testing

3. Benefits of M&S.

a. The Tactical Missile Signature (TMS) center and database at Arnold Engineering Development Center (AEDC) reports that obtaining the measurements for various missile characteristics can cost up to $700,000 per missile to set up, fire, and collect and reduce the data. Equivalent data can be obtained using M&S tools for less than $10,000.

b. The F-22 program used AEDC's integrated T&E (IT&E) concept to address the need to safely separate fuel tanks and weapons from the aircraft over a range of flight conditions. Modeling of the pylons and the maneuvering aircraft were combined and compared to wind tunnel model scale data. The degree of correlation validated the approach and allowed ground simulation results equivalent to flight conditions. The IT&E approach met the goals of reduced cost and increased information to reduce program risk. In addition to providing the information, this approach saved the F-22 program a verified $8 million.

c. AEDC used combined computational fluid dynamics (CFD) and engineering methods to predict the separation of the Pegasus XL rocket booster from an L-1011 Tristar aircraft without having to conduct wind tunnel testing that would have cost about $750,000.

d. Testing of stockpiled munitions, for systems such as HELLFIRE and Javelin, is required to ensure their reliability after storage. M&S techniques coupled with non-destructive electronic component testing has dramatically reduced the number of live missile firings required to certify reliability of a stockpiled lot.

e. Advanced Medium Range Air-to-Air Missile (AMRAAM) testing at the Guided Weapons Evaluation Facility (GWEF) at Eglin AFB used M&S to simulate between 16,000 and 17,000 missile software and hardware tests. This testing was not feasible using live firings due to the high cost (about $3M for each missile). The needed data could not be obtained unless M&S was used.

f. Navy in-water torpedo testing can cost from $50,000 to $80,000 per firing, while the used of simulation can allow 100 to 300 tests to be run for the same price.

g. Navy live-fire missile testing produces fewer than 100 data points on average, and hundreds of thousands of such data points are needed to adequately describe missile performance envelopes. Since fewer than 25 valid live firings are usually affordable, the only alternative is the use of simulation.

h. An analysis of the HWIL facility at Point Mugu, CA for AMRAAM testing claims a cost avoidance of $2,500 million a year (assuming that 8,400 (the number of simulated firings) live firings per year was feasible). The same analysis reveals that the Weapons Software Support Facility (WSSF) at China Lake provides a cost avoidance of about $10 million a year. WSSF is used for integration, checkout, and V&V of avionics software with actual avionics hardware operating as a total aircraft system. The conclusion is that it is impossible to rigorously test systems as complex as F/A-18 avionics without this type of facility, not only from the point of view of cost, but also with regard to safety, accuracy, environmental concerns, security/stealth, training, and other factors.

i. During SIMNET/AIRNET Developmental and Operational Testing for Army helicopters, two Non-Line of Sight (NLOS) simulators were built and compared with captive flight and actual missile firing tests. The results showed that total costs for the necessary testing was about $6.65M for captive flight, $8.8M for live missile firing, and $2M for the simulators. The simulators had major advantages in the number of trials that were completed, and the reduced time and number of test personnel required.

j. The US Army Missile Command (MICOM), RD&E Center, Advanced Simulation Center Hardware-in-the-Loop Simulation Facilities, claim total cost savings/avoidance that exceed $270M.

k. US Army TECOM has documented the following benefits derived from M&S, for ground weapon systems:

- The Firing Impulse Simulator (FIS) simulates the recoil/trunnion loads and ballistic shock effects for tank and howitzer cannons. The investment cost was almost $7M, but the FIS saves about $2,000 per round or $23M in cost avoidance for a typical trunnion bearing test. There are also savings from reduced personnel (13 to 4), time savings, and reduced environmental problems in terms of noise, blast, and toxic fumes for each test.
- The Moving Target Simulator (MTS) assesses the ability of tank and other weapon crews to track and fire on simulated maneuvering targets (represented by projected laser spots). The MTS saves about $1.5M per year compared to field tests, and also significantly reduces time spent on test, redesign, and retest.
- Bridge durability testing was once done by 3,000 actual crossings over a period of 12 weeks and at a cost of about $325,000. Such tests are now conducted using a mix of actual and simulated crossings based on instrumented degradation. The new method reduces cost to about $110,000 and time to about 9 weeks.
- Vibration Test Facility (VTF) shaker tables can now replace actual miles driven by combat vehicles to determine the effects of vibration. This saves costly field testing, as each tank hour of driving costs about $1,200.
- Target Acquisition Model Improvement Program (TAMIP) provides an objective means for comparing the vulnerability of vehicles to detection on the battlefield. The models quantify the value added when vehicle signatures are reduced. Included in TAMIP improvement are millimeter wave, infrared, visible, and acoustic models.

l. The AFFTC at Edwards AFB, CA, primarily conducts developmental flight tests to clear aircraft and electronic warfare (EW) systems for operational testing. Benefits are significant, but hard to quantify:

- Immediate cost savings from M&S use in flight test are not significant compared to the long term (cost avoidance) savings to the program from more effective and timely elimination of problems, especially before fielding the aircraft (after which changes become very expensive).
- M&S tools are essential to investigating issues of flight safety before live range testing with humans.

- In recent years using M&S tools at Edwards, there were no major problems encountered in live flights that were not identified early in pre-test simulations by those tools.
- M&S helps to focus the available test time much more productively and reduces risk.

m. NAWCWPNS, China Lake, CA, is the Navy's full spectrum RDT&E and in-service engineering center for weapons systems associated with air warfare (except antisubmarine warfare systems), missiles and missile subsystems, aircraft weapons integration, and assigned airborne EW systems. A range of facilities within the NAWCWPNS provide important data in the areas of target signatures, acquisition and tracking, end-game geometry, weapon lethality, proximity sensor detection characteristics, target resistance to fusing, avionics integration, pilot interactions, radar and sensor integration, GPS integration, situational awareness, rules of engagement, radio frequency (RF) and infrared (IR) signatures, and other types of data. Identified benefits include:

- M&S is an enabling tool without which much of the acquisition process cannot be accomplished as it allows understanding of engineering and operational issues including difficult systems integration issues; assessment of scenarios which are impossible to actually test; and evaluation where security considerations preclude 'open air' testing.
- M&S avoids the cost of some live fire test failures which typically result in program schedule slips and unanticipated costs, or high visibility failures which threaten life as well as program viability, and other aspects of risk.
- M&S avoids Software Support Activities (SSA) startup costs after production ends.
- M&S reduces costs by focusing test firings.

n. Sikorsky projects that for the Comanche helicopter program they will save $673M through the use of virtual prototyping over actual flight test hours involving crew station and flight controls design, major equipment integration, air worthiness qualification and training.

o. A vulnerability assessment was required for each of the 15 primary targets for the Joint-Service Standoff Weapon (JSOW). The Navy conducted full-scale tests on only three of the targets to validate and calibrate M&S tools. The tools were then used to conduct the analyses of the remaining 12 targets without further full-scale tests. This approach saved more than $2.5M.

p. At AEDC, M&S has been used to help lower the cost of testing to the customer. Average time in the PWT-16T wind tunnel has decreased from six weeks to 3-4 days.

q. At Eglin AFB, use of PRIMES (Preflight Integration of Munitions and Electronic Systems) ground simulation led to a 35% reduction in cost and a 300% increase in data capture during a recent flight test program of the APG-63 radar.

r. The Patuxent River Naval Air Warfare Center Aircraft Division (NAWCAD) used state-of -the-art simulation and ground test capabilities to reduce flight test hours and costs by a third while evaluating ALQ-99 receivers and ALQ-149 communications countermeasures equipment on board the EA-6B aircraft.

s. The F-16 program has used AFFTC M&S facilities to evaluate avionics and electronic suites since 1990 as a replacement for and complement to flight test programs. Approximately $40.8 million have been saved on flight tests with this approach.

t. M&S tools were used to test the F-15 radar, providing three times the data at a third of the cost compared to open air range testing. A small number of flight tests were used to validate the results.

E. Manufacturing Process

Emphasis and investment in automation has improved the efficiencies of the manufacturing process, but its lack of integration with other development processes is the root problem. Particularly in the defense industry where emphasis is on design and innovative technology, manufacturing has suffered in priority and emphasis.

1. Tools in the Evolving Manufacturing Process

The primary contribution of emerging M&S tools is not in improved manufacturing technologies, but rather in bringing manufacturing expertise to the design processes so that the final design is more manufacturable. Improved manufacturability offers significant potential payoff.

In addition, M&S tools can assist the manufacturing team in designing the manufacturing process for a new system just as the design team is developing the design. The equipment, work flow, and overall process for manufacturing can now be developed and analyzed in a virtual environment with high confidence in the results.

2. Metrics.

- number of available options to improve cost, schedule, performance, etc.
- reduction in number of manufacturing process steps and time
- better part and assembly fit resulting in less need for rework
- reduced labor costs including fewer meetings and data submittals
- reduced amount of scrap and waste material

3. Benefits of M&S.

a. The Comanche program used the Computer Aided Three-Dimensional Interactive Simulation (CATIA) package to improve on the traditional design and manufacturing processes. For joining the fuselage and tailboom, this facilitated a two-step tooling process versus an eightstep process as experienced in the CH-53 program without use of CATIA. It also achieved 95% first time fit versus 35% in previous processes, and reduction of labor cost for the joining from 19 man-years to one man-month.

b. The Joint Strike Fighter (JSF) PM Office and McDonnell Douglas conducted a six-month side-by-side comparison of traditional versus virtual manufacturing (VM), involving redesign of the F-15E mid-fuselage airframe former. Benefits attributed to the VM approach were:

- 33% reduction in design release time,
- 27% reduction in cost,
- 19% reduction in manufacturing cycle time,
- 20% reduction in factory floor space use,
- a higher quality production part including 24% reduction in parts count and 78% reduction in fasteners required for assembly.

The JSF PM Office projects the benefits of VM offer a potential savings of up to 3% of life cycle costs which could equate to $5 billion.

c. Through computer-based concurrent engineering and improved communications within and among design teams, Intel Corporation has reduced the time for hardware from design-to-sample in half, even though product complexity doubled. In addition, the company has achieved a 95% success rate on the first silicon fabrication of new products.

d. For the Army's Flexible Computer Integrated Manufacturing (FCIM) program, the Electronics Module communications end items effort has resulted in:

- 66% reduction in cycle time,
- $3 million in cost savings,
- $3.8 million in cost avoidance.

e. Electronically integrated data among several departments permitted Ford Motor Company to increase its quality such that there was a 10-15% cost reduction and a 14% reduction in time for sheet metal production. Currently, Ford is on track toward its goal of 90% reduction in the number of prototype manufacturing models that it must build.

f. The use of integrated CAD systems by Northrop led to a first-time, error-free physical mock-up of many B-2 sections. Use of CAD also assisted in achieved first-time correct tube bends for expensive titanium electronic cable conduits.

g. Boeing Corporation, using new M&S tools and processes on the 777 aircraft, was able to make necessary tooling changes with only two engineers instead of 40 engineers required for previous aircraft.

h. Boeing reports that their 747 required over 10,000 shims to compensate for ill-fitting parts while the 777 requires fewer than 50 shims. After leaving the assembly line, the 747 required many hundreds of workers to complete unfinished tasks, while the 777 required only a few workers.

i. Boeing reports that scrap was reduced by 30% on the 777 compared to the 747. Rework was reduced from 30% on the 747 down to 3% on the 777.

j. The JSF program reconfigured one component that was initially comprised of 250 parts into a design of only 25 parts which significantly reduced manufacturing and support costs.

F. Deployment and Support Process

Operation and support (O&S) of a deployed system typically requires a majority of the total life cycle costs of the system. The cost of maintaining the system is a function of many factors including the maintenance time required, and the production and storage costs of repair parts. Too often these O&S costs have not been adequately considered by the design team which is driven by operational performance requirements.

1. Tools in the Evolving Deployment and Support Process.

As in previous phases, the significant change made possible by the use of M&S tools is to integrate these O&S functions into the total system development process. That primarily means considering the implications of these functions on the concept which is selected and the design which is developed to satisfy operational requirements. Not only can operational use be evaluated during the design stages to minimize the subsequent necessity for modifications to the fielded systems, but the support requirements for those systems can be better analyzed during the design stage to lessen the support burden and thus the total life cycle costs of the system.

2. Metrics.

- time to evaluate Operations and Support (O&S) costs and issues
- time to analyze/create O&S requirements such as planning documents
- amount of data stored and accessed
- number of legacy designs, products, or tools re-used

3. Benefits of M&S.

a. The Navy's Smart Product Model (SPM) is designed to support all phases and functions of acquisition including O&S needs. For the NSSN program, early analysis of form, fit and function integrates representatives from the fleet in order to ensure they can provide input to how design and manufacturing will impact future maintenance and support activities.

b. Lockheed Martin Corporation indicates that M&S support in the areas of supportability evaluation will reduce maintenance man-hours by up to a factor of three.

c. Electronic integration by Northrop permitted the reduction of provisioning list release time from six months to 60 minutes.

d. For the McDonnell Douglas AH-64D Longbow Apache program, the Engineering Development Simulator (EDS) was initially used for the source selection effort, then was further developed and verified and validated to support development, prototype production, and testing. The EDS or legacy systems built upon the EDS such as the LCT (Longbow Crew Trainer) are now used for aircraft training. The MAVWEST (Multiplex Armament Visionics, Weapons and Electrical System Trainer) uses hardware and software developed for the LCT and other early legacy systems. MAVWEST is used for high complexity maintenance training for a range of systems including fire control radar, armament, navigation, and communications.

e. With the Navy's focus on life cycle maintenance, new M&S tools have helped to reduce the standard parts list from about 95,000 for the Seawolf class submarine to about 16,000 for the NSSN.

f. A study of the impact of a common data management, storage, retrieval and exchange service for transferring in a standard digital format all contractor design and manufacturing data among the Air Force and its B2 subcontractors found significant savings. This study, "CALS Contractor Integrated Technical Information Service (CITIS): Business Case Feasibility Study," determined that the CITIS would lead to:

- 50% reduction in attendees at meetings between contractors and the Air Force,
- 5.4% reduction in the total B2 spare parts dollars,
- 23% reduction in modification lead time,
- 1.8% increase in the average availability of the aircraft fleet, and
- 90% reduction in the contractor data submittals.

The total estimated cost savings ranged from a minimum of $536M to a maximum of $894M, for investments that ranged from $9M to $30M.